METAL AND METAL OXIDE NANOPARTICLES SYNTHESIZED FROM GREEN MATERIALS FOR LATENT FINGERPRINT DEVELOPMENT

Research Protocol

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INTRODUCTION

In the expansive realm of forensic science, the identification of individuals remains a fundamental pillar of criminal investigations. Among the various tools employed for this purpose, fingerprints have emerged as one of the most reliable and infallible means of personal identification. This reliability stems from the absolute uniqueness and permanence of fingerprint patterns, which form the scientific basis of a sub-discipline known as dactylography**(Ashbaugh, 1999).** These patterns, which appear not only on the fingertips but also on palms, soles, and toes, begin to form during early embryonic development—specifically from the 6th week of gestation and become fully developed by the 21st week of intrauterine life. Remarkably, they remain unchanged throughout an individual's lifetime, making them an ideal biometric trait for forensic applications **(Cummins &Midlo, 1943).**

What makes fingerprints particularly compelling in forensic science is that no two individuals, not even identical twins, have ever been found to share the same pattern **(Galton, 1892).** This profound individuality enables fingerprint evidence to act as a silent witness, linking individuals to crime scenes with unparalleled precision. When a person touches a surface, they may unintentionally leave behind latent fingerprints—invisible impressions formed due to the secretions of eccrine, apocrine, and sebaceous glands combined with external contaminants **(Ramotowski, 2012).**

Among these, the eccrine glands, most abundantly found in the palms and soles, are of particular forensic significance. These glands secrete a complex mixture of water, salts, amino acids, lipids, urea, sugars, fatty acids, and other organic and inorganic compounds**(Braga et al., 2010).** When these secretions are deposited on surfaces, they form the basis of latent fingerprints. However, visualizing these prints poses a significant challenge, particularly when they are faint, aged, or deposited on complex surfaces.

To overcome this, forensic experts employ various development techniques, generally categorized into physical, chemical, and optical methods. The most common physical method is powder dusting, which uses finely milled materials—such as carbon black, metallic particles, or magnetic powders—to adhere to the moisture or oily residues of the fingerprint, thereby

revealing ridge patterns (**Jasuja & Singh, 2009).**Chemical techniques include iodine fuming, silver nitrate, and ninhydrin, among others. For instance, ninhydrin reacts with amino acids in fingerprint residues to produce a purple compound called Ruhemann's purple**(Cantu, 2001).** Another widely used method is cyanoacrylate fuming, where vaporized superglue polymerizes on the fingerprint residues, forming a hard white matrix that reveals ridge details (Sears et al., 2006). Fluorescent dyes and alternative light sources are also used to enhance visualization, especially on multicolored or dark surfaces **(Champod et al., 2016).**

Despite their success, these conventional methods have several limitations. Their efficiency varies significantly with the age of the print, the type of surface, and environmental exposure**(Ramotowski, 2012).** More critically, many of the reagents involved—such as iodine, silver nitrate, ninhydrin, and cyanoacrylate—pose significant health and environmental hazards. Studies have shown that prolonged exposure to these chemicals can result in respiratory irritation, skin burns, neurotoxicity, and allergic reactions**(Rubenzer, 2003).** Moreover, their volatile and carcinogenic nature necessitates controlled laboratory environments with adequate ventilation and protective equipment.

From an ecological perspective, the use of these toxic and non-biodegradable chemicals has raised serious concerns about their impact on the environment. Improper disposal can result in soil and water contamination, bioaccumulation in flora and fauna, and long-term damage to ecosystems **(Anastas & Warner, 1998).** In developing countries or poorly equipped forensic labs, the risks to both human health and the environment are further magnified due to a lack of proper safety protocols and waste management systems.

In response to these challenges, the forensic science community is increasingly turning to green chemistry—a discipline that emphasizes the design of products and processes that minimize the generation and use of hazardous substances. This paradigm shift has opened the door for the application of nanotechnology, particularly in the form of nanoparticles, to develop more efficient and environmentally sustainable fingerprint detection methods.

Nanotechnology, defined as the manipulation of materials at the nanometer scale (1–100 nm), offers several advantages for forensic applications. Nanoparticles possess unique physical,

optical, and chemical properties, such as high surface area, quantum effects, and strong fluorescence, which allow them to interact effectively with fingerprint residues and improve contrast and clarity**(Sharma et al., 2011).** However, traditional synthesis methods for these nanoparticles often involve hazardous chemicals like sodium borohydride or hydrazine, which contradict the principles of green chemistry **(Iravani et al., 2014).**

To reconcile this, researchers have begun to explore green synthesis techniques for nanoparticle production. This involves using biological materials, particularly plant extracts, as both reducing and stabilizing agents. These extracts are rich in flavonoids, alkaloids, tannins, saponins, phenolics, terpenoids, and proteins, which facilitate the conversion of metal salts into stable nanoparticles in an eco-friendly manner **(Ahmed et al., 2016).** The bottom-up approach of green synthesis not only reduces environmental impact but also allows for fine control over particle size, shape, and crystallinity—key factors influencing their efficiency in fingerprint development **(Mittal et al., 2013).**

Several studies have demonstrated the effectiveness of green-synthesized nanoparticles in enhancing latent fingerprint detection. For example, silver nanoparticles synthesized using plant extracts have shown strong luminescence properties, enabling clear visualization of ridge patterns under UV and visible light**(Bhargava et al., 2013).** Similarly, metal oxide nanoparticles such as zinc oxide, titanium dioxide, and iron oxide synthesized via green methods have been successfully applied on both porous and non-porous surfaces, even detecting aged or faint fingerprints**(Zhou et al., 2016).** These nanomaterials not only improve detection sensitivity but also reduce health risks, are cost-effective, and align with the global movement toward sustainable science.

Given this context, the present research is focused on the green synthesis of nanoparticles using plant-based materials to develop metal, metal oxide and silica-based nanoparticles. The study aims to assess their physicochemical properties—including particle size, morphology, stability, and optical characteristics—and to evaluate their efficacy in latent fingerprint development on a variety of surfaces.

This approach not only contributes to the advancement of forensic technology but also promotes eco-conscious practices in crime investigation. By integrating the principles of green chemistry, nanotechnology, and forensic science, this research aspires to develop a sustainable, safe, and efficient method for latent fingerprint visualization, thereby supporting the broader global mission of environmental responsibility and public health protection in scientific practice.

STUDY AREA

In recent years, the field of forensic science has witnessed growing interest in the application of nanotechnology, particularly the use of metal and metal oxide nanoparticles, for the development of latent fingerprints. Among these, green synthesis of nanoparticles has emerged as a sustainable and eco-friendly approach, aligning with the global shift towards environmentally benign technologies. Green materials—such as plant extracts, microorganisms, and other biological agents—serve as natural reducing and stabilizing agents for synthesizing nanoparticles, offering a non-toxic alternative to conventional chemical methods.

Metal and metal oxide nanoparticles, including silver (Ag), gold (Au), zinc oxide (ZnO), titanium dioxide (TiO_2), iron oxide (Fe_3O_4), and silica (SiO_2), possess unique optical, chemical, and surface properties that make them highly effective for fingerprint visualization. Their nanoscale size and high surface area facilitate strong interactions with the components of latent fingerprints, including sweat residues, lipids, and amino acids. These interactions enhance the contrast and clarity of fingerprint ridges on various substrates, ranging from porous to non-porous surfaces.

While metal and metal oxide nanoparticles have shown promising results, **silica-based nanoparticles synthesized via green methods are also gaining momentum** due to their biocompatibility, surface functionalization ability, stability, and ease of synthesis. Silica nanoparticles can serve as excellent carriers or matrices for other active nanomaterials, and their tunable porosity can be exploited to trap and bind fingerprint residues efficiently. Therefore, this study will also focus on the **synthesis and application of green-synthesized silica-based nanoparticles** for latent fingerprint development.

Despite these advantages, traditional nanoparticle synthesis methods often involve toxic solvents, high energy inputs, and hazardous by-products, posing risks to both the environment and forensic practitioners. Green synthesis addresses these issues by providing an energy-efficient, cost-effective, and sustainable route to nanoparticle production, without compromising their functional efficiency. However, challenges still remain in terms of achieving uniform particle size, long-term stability, reproducibility, and selective binding to fingerprint residues.

To overcome these limitations, ongoing research is exploring the functionalization of green-synthesized nanoparticles and their integration with novel carriers or matrices for improved adherence and development of latent prints. Furthermore, advancements in characterization techniques such as SEM, TEM, FTIR, and XRD have enabled deeper understanding of the physicochemical interactions between nanoparticles and fingerprint residues.

The development of **metal, metal oxide, and silica-based nanoparticles derived from green materials** not only enhances the sensitivity and selectivity of fingerprint development but also aligns with the principles of green chemistry and sustainability in forensic applications. Therefore, this study focuses on synthesizing and characterizing eco-friendly nanoparticles for their potential application in effective, non-destructive, and affordable latent fingerprint development on diverse forensic substrates.

PURPOSE OF STUDY

- To explore the use of green-synthesized metal and metal oxide nanoparticles as an environmentally sustainable alternative for latent fingerprint development, reducing reliance on hazardous chemicals.
- To improve the sensitivity, precision, and resolution of latent fingerprint visualization on diverse substrates, enhancing the efficiency of forensic investigations.
- To promote the adoption of green synthesis methods in forensic science, aligning with global sustainability initiatives and reducing environmental impact.
- To systematically characterize green-synthesized nanoparticles using advanced analytical techniques to understand their size, morphology, surface properties, and functionality.

- To assess the performance of green-synthesized nanoparticles in latent fingerprint development and compare their efficacy with conventional methods in terms of visualization quality and substrate compatibility.
- To develop a non-invasive and non-destructive method for latent fingerprint visualization, ensuring the integrity of forensic evidence for further analysis.
- To establish a research framework that integrates the advancements of nanotechnology with practical applications in forensic science.
- To contribute to the limited body of research on the interaction mechanisms between green-synthesized nanoparticles and fingerprint residues, paving the way for future studies.
- To create a fingerprint development technique that is versatile and effective across a wide range of environmental conditions and substrate types.
- To provide a foundation for incorporating sustainable forensic practices into academic curricula and professional forensic investigations.

OBJECTIVES OF RESEARCH WORK

The present research proposal has various objectives and few of them may be highlighted as follows:

1. To extractnatural products from Green Materials.
2. To synthesize metal and metal oxide nanoparticles using eco-friendly green materials,
3. To analyze the physical, chemical, and structural properties of the synthesized nanoparticles using advanced techniques like SEM, TEM, XRD, FTIR, and UV-Vis spectroscopy.
4. To evaluate the effectiveness of green-synthesized nanoparticles in visualizing latent fingerprints on diverse substrates, ensuring high resolution, contrast, and sensitivity.
5. To evaluate the effect of size and shape of nanoparticle on fingerprint development.

STATEMENT OF RESEARCH PROBLEM

“METAL AND METAL OXIDE NANOPARTICLES SYNTHESIZED FROM GREEN MATERIALS FOR LATENT FINGERPRINT DEVELOPMENT”

REVIEW OF LITERATURE

In recent years, the field of forensic science has witnessed considerable advancements in the development of green-synthesized nanoparticles for latent fingerprint (LFP) detection. The shift from conventional, chemically intensive methods to more sustainable approaches has been driven by the need for non-toxic, eco-friendly, and cost-effective alternatives that do not compromise detection quality.One of the significant breakthroughs was presented by **Madhavan and Kumar Sharma (2019)**, who synthesized iron oxide nanoparticles using *Camellia sinensis* (green tea) leaf extract. These biosynthesized nanoparticles exhibited excellent performance in visualizing latent fingerprints on both porous and non-porous surfaces, producing distinct ridge patterns with enhanced contrast. The study emphasized the advantages of this approach, including its eco-friendliness, cost-effectiveness, and high stability, making it a viable solution for real-world forensic applications.Similarly, **Rajan et al. (2019)** explored the potential of lithium-doped zinc oxide nanoparticles synthesized using *Azadirachtaindica* (neem) extract for fingerprint development. The synthesized nanoparticles, with sizes less than 100 nm, showed exceptional ridge detail and contrast, particularly on dark-colored non-porous surfaces. The research also highlighted the potential to optimize these nanoparticles for enhanced photoluminescence and dispersity, paving the way for future improvements.

In a novel approach, **Prabakaran and Pillay (2019)** developed a nanocomposite material combining nitrogen-functionalized carbon dots (N-CDs) and zinc oxide nanoparticles (ZnONPs) synthesized using plant-based waste such as potato peels. The resulting nanocomposite demonstrated superior sensitivity and selectivity in detecting LFPs on non-porous substrates, producing high-contrast images with fluorescence under UV light. This innovation underscored the potential of sustainable and biodegradable nanomaterials in forensic science.Expanding on the use of metal oxide nanoparticles, **Bhagat et al. (2020)** synthesized copper oxide

nanoparticles (CuO-NPs) using green tea extract via an ultrasonic-assisted method. The nanoparticles were successfully applied to fingerprint development on glass, steel, and paper surfaces using the powder dusting technique. Their non-toxic, non-corrosive, and eco-friendly properties make them ideal for crime scene applications.A critical review by **Prabakaran and Pillay (2021)** offered comprehensive insights into the use of various nanomaterials in fingerprint detection. Their analysis covered metal nanoparticles, metal oxide nanoparticles, quantum dots, carbon dots, and rare-earth-based fluorescent nanoparticles. The review discussed the performance, advantages, and limitations of each category, stressing the necessity for ongoing research to enhance ridge clarity and detection across various substrates.

The use of agricultural waste for nanoparticle synthesis was explored by **Rajan et al. (2020)**, who developed fluorescent silica nanoparticles (SiNPs) from rice husk. These mono-dispersed nanoparticles (200–400 nm), when doped with curcumin, showed promising fluorescence and were effective in detecting fingerprints on multicolored surfaces.Continuing the trend of green synthesis, **Zargham et al. (2024)** employed lemongrass extract to synthesize ZnO nanoparticles. Their formulation demonstrated successful fingerprint visualization up to 24 hours post-deposition, with clear ridge detail observed on a variety of substrates, indicating the potential for time-sensitive forensic investigations.Further exploration by **Bhagat et al. (2021)** led to the green synthesis of CuO nanoparticles using green tea extract. With particle sizes ranging from 500 to 900 nm, the material provided high contrast and clarity for fingerprint development across diverse surface types, reinforcing its forensic utility.

The potential of silica-based materials was further explored by **Bhati et al. (2023)**, who employed a green micro-emulsion templating method to synthesize biocompatible SiNPs with particle sizes of 100–150 nm. These particles exhibited high cell viability and excellent visibility of fingerprints under UV light, particularly on non-porous surfaces.In another notable study, **Oliveira et al. (2024)** synthesized fluorescent silica nanoparticles, achieving a 94% success rate in latent fingerprint detection. The versatility of these nanoparticles across various substrates emphasized their effectiveness and adaptability in practical forensic scenarios.In a unique approach, **Raju et al. (2024)** utilized rice husk-derived iron oxide nanoparticles doped with eggshell to synthesize red luminescent materials. The materials were non-toxic and highly efficient in fingerprint visualization, offering a bio-compatible solution for forensic use.The

synthesis of hybrid nanoparticles was explored by **Sekhar et al. (2021)**, who embedded zinc oxide-carbon dot hybrids into silica gel. The resultant nanomaterials possessed multi-fluorescent properties, enhancing fingerprint visualization on up to 19 different substrates, highlighting their adaptability and broad-spectrum utility.Finally, **De Araujo et al. (2024)** synthesized fluorescent silica-based materials from rice husk ash and functionalized them with various dyes. These particles provided high contrast fingerprint development under UV light, contributing to a new generation of sustainable and efficient detection tools.

Collectively, these studies illustrate the growing momentum in green nanotechnology for forensic science, particularly in the domain of latent fingerprint visualization. With continuing innovations and refinement, green-synthesized nanoparticles are poised to become a mainstay in sustainable forensic investigations.

RESEARCH METHODOLOGY:

This research adopts a systematic and eco-conscious approach rooted in green chemistry principles to synthesize, characterize, and apply both metal nanoparticles (MNPs) and metal oxide nanoparticles (MONPs) derived from plant-based materials for the development of latent fingerprints. The methodology is designed not only to ensure sustainability and cost-effectiveness but also to maximize the sensitivity and reproducibility of results when applied in forensic contexts.

The methodology illustrated in the figure 1 focuses on the green synthesis of metal nanoparticles by utilizing plant waste as a reducing and stabilizing agent. This process begins with the collection of green waste, which may include household or agricultural plant materials. These raw materials are initially subjected to a preparatory treatment involving thorough washing to remove dirt and impurities. The cleaned plant matter is then dried and boiled in distilled water to extract its bioactive compounds, which contain phytochemicals like flavonoids, terpenoids, polyphenols, and alkaloids that can facilitate the reduction of metal ions.

The extract obtained is then filtered to remove solid debris, yielding a clear plant extract. Simultaneously, a metal ion precursor solution is prepared by dissolving appropriate metal salts (such as copper sulfate, zinc nitrate, or ferric chloride) in distilled water. This solution acts as the

source of metal ions that will be reduced to nanoparticles. The plant extract is added dropwise into the metal ion precursor under continuous stirring. This slow addition allows a controlled reaction, which is crucial for the formation of uniformly sized nanoparticles.A distinct color change in the solution indicates the successful reduction of metal ions and the formation of metal nanoparticles. The color change arises due to surface plasmon resonance, a phenomenon typical of nanoparticles. Following the reaction, the colloidal solution is subjected to centrifugation to separate the synthesized nanoparticles from the reaction mixture. The collected particles are then washed with distilled water and ethanol to remove any unreacted biomolecules and dried to yield a fine nano- powder.

This dried nanopowder is then characterized using various analytical techniques such as UV-Vis spectroscopy, Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and X-ray diffraction (XRD) to determine particle size, shape, elemental composition, and functional group interactions.Finally, the prepared nanoparticles are used for latent fingerprint (LFP) development on both porous and non-porous surfaces. By dusting the nanopowder onto fingerprint residues and visualizing under visible or ultraviolet light, clear ridge patterns can be observed. These nanoparticles not only enhance contrast and detail but also provide a non-toxic, biodegradable, and eco-friendly alternative for forensic fingerprint development.

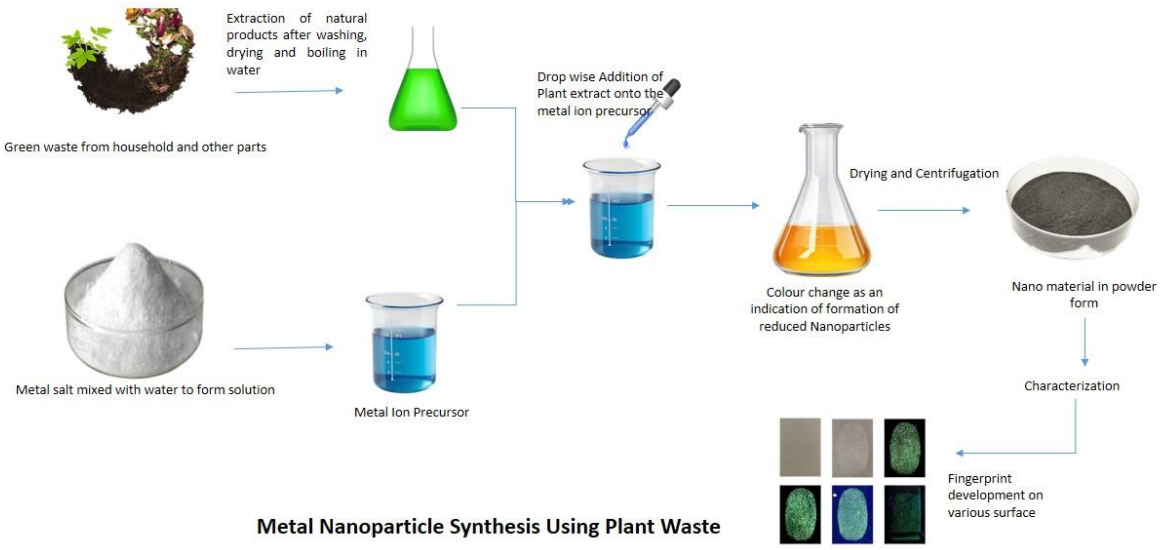
Extraction of natural products after washing, drying and boiling in water
Green waste from household and other parts
Drop wise Addition of Plant extract onto the metal ion precursor
Drying and Centrifugation
Colour change as an indication of formation of reduced Nanoparticles
Nano material in powder form
Characterization
Fingerprint development on various surface
Metal salt mixed with water to form solution
Metal Ion Precursor
Metal Nanoparticle Synthesis Using Plant Waste

Figure 1 – Synthesis of Metal Nanoparticle using Green Source for Latent Fingerprint Development

The figure 2 presents a more specialized and structured methodology involving the synthesis of **silica-based nanoparticles** derived from **silica rich waste**, tailored specifically for latent fingerprint development. The process begins with the collection ofsilica rich waste material, an abundant agricultural byproduct known for its high silica content. This is then cleaned, dried, and then subjected to calcination or thermal treatment at high temperatures. This step removes organic matter and converts the husk into husk ash, which primarily contains amorphous silica.

The ash is then treated with an alkaline solution, typically sodium hydroxide (NaOH), to extract silica in the form of sodium silicate. This sodium silicate solution undergoes acidification—often by adding hydrochloric acid or sulfuric acid—under controlled pH and temperature conditions to precipitate silica particles. The resulting gel is aged, washed thoroughly, and dried to obtain pure silica nanopowder.

To enhance the optical and fluorescent properties of the synthesized silica, doping agents such as curcumin or rare-earth dyes may be incorporated during or after the synthesis. This process

ensures that the final product exhibits strong fluorescence under UV light, a key feature for visualizing latent fingerprints on multicolored or dark substrates.

The obtained fluorescent silica nanoparticles are then subjected to **ultrasonication** to break up agglomerates and obtain uniform dispersion. The solution is again centrifuged to isolate nanoparticles of the desired size, generally ranging from 100 to 400 nm. Post-centrifugation, the nanoparticles are dried and stored as a powder.

These silica nanoparticles are then applied to latent fingerprints on various non-porous surfaces, such as glass, plastic, and metal, using standard dusting methods or suspension techniques. When exposed to ultraviolet light, the doped fluorescent particles adhere to the sweat and oil residues in the fingerprint ridges, producing high-contrast images with exceptional clarity. The process is non-invasive, biocompatible, and suitable for practical forensic applications. Additionally, the method aligns with sustainability principles by valorizing agricultural waste while minimizing environmental impact.

Silica Rich waste
Washing and drying
Digestion by using acids over hot plate to extract the filtrate
Filter and rinse thoroughly with deionized (DO) water
Dry the filtrate at 90°C
Calcine the black rice husk ash in a furnace at 700°C for 5 hours. Obtain pure white ash.
Dissolve 0.5 g of pure white ash in 100 mL of 1 M NaOH
Heat the solution at 80°C under constant stirring for 1 hour
Precipitation and pH Adjustment
Centrifugation and drying
Age sodium silicate solution in the oven at 80°C overnight. Precipitate and dry to get the metal oxide nanoparticle
Characterization
Fingerprint development on various surface
Metal Oxide Nanoparticle synthesis through silica rich plant waste

Figure 2 – Synthesis of Metal-Oxide Nanoparticle Using Silica Rich Green Source for Latent Fingerprint Development

With the synthesized and characterized nanoparticles prepared, the final phase of the research involves their application in forensic science, specifically in the development of latent fingerprints on various substrates. Substrates such as glass, plastic, steel, and paper are selected to simulate a range of porous and non-porous surfaces typically encountered at crime scenes. Natural latent fingerprints are deposited on these surfaces under controlled conditions. The synthesized nanomaterials are then applied to the fingerprints either as a fine powder using conventional dusting techniques or as a colloidal suspension via spraying or immersion.

Upon application, the nanoparticle-coated fingerprint ridges are allowed to dry. Visualization is then carried out using either white light or UV illumination, depending on whether the nanomaterials exhibit fluorescence properties. Photographic documentation of the developed prints is carried out using a high-resolution camera. The clarity, contrast, and visibility of the fingerprint ridges, including minutiae details such as bifurcations and ridge endings, are analyzed and compared with traditional fingerprint powders to evaluate the efficiency of the synthesized nanomaterials.

This methodological approach allows for the successful integration of environmentally friendly practices with forensic nanotechnology. The utilization of plant waste ensures low-cost, non-toxic synthesis of nanoparticles, while the comprehensive characterization ensures scientific rigor and reproducibility. Ultimately, the effective development of high-clarity latent fingerprints on various surfaces validates the applicability of green-synthesized MNPs and MONPs in real-world forensic investigations.

SOCIAL RELEVANCE

In an era where sustainability and technological innovation must go hand-in-hand, the proposed research holds deep social relevance by addressing critical challenges in both forensic science and environmental responsibility.

Latent fingerprints are one of the most vital forms of trace evidence in crime scene investigations, enabling the identification and conviction of offenders. Traditional fingerprint development methods, though effective, often involve the use of hazardous chemicals and synthetic reagents that pose risks to human health and the environment.

This research introduces a **green nano technological approach** for developing metal and metal oxide nanoparticles using **biological waste materials** many of which are discarded as household or agro-waste. By converting this waste into high-value forensic materials, the study not only **minimizes chemical hazards** but also promotes **sustainable waste management**.

Moreover, the use of biogenic nanoparticles is expected to offer better performance in fingerprint visualization, especially on difficult surfaces and aged prints, leading to **more efficient crime detection and justice delivery**. The cost-effective and eco-friendly nature of these materials also ensures their accessibility for **resource-limited forensic laboratories**, especially in developing nations.

In summary, the research advances forensic practices in an environmentally responsible direction, encourages waste-to-wealth innovations, and aligns with global goals of **sustainable development**, **public safety**, and **judicial effectiveness**.

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